

## WHAT IS CLAIMED IS:

### 1. An apparatus comprising:

5           a check bit encoder circuit coupled to receive a data block, wherein the check bit encoder circuit is configured to generate a corresponding encoded data block comprising the data block, a first plurality of check bits, and a second plurality of check bits; and

10           a check/correct circuit coupled to receive an encoded data block, the check/correct circuit configured to detect an error in data from one of a plurality of components and correct the error using the first plurality of check bits, the second plurality of check bits, and the data block within the encoded data block;

15           wherein the encoded data block is logically arranged as an array of R rows and N columns, wherein R and N are positive integers, and wherein each of the N columns comprises data bits from a respective one of the plurality of components, and wherein the first plurality of check bits form a first column of the array, and wherein each of the first  
20           plurality of check bits covers a row of the array, and wherein the second plurality of check bits form a second column of the array and are defined to cover bits in the array according to a plurality of check vectors, each of the plurality of check vectors corresponding to a different bit in the array, and each of the plurality of check vectors is an element of a Galois Field ( $GF(2^R)$ ), and wherein the plurality of check vectors are  
25           derived from a plurality of unique elements of  $GF(2^R)$ , each of the plurality of unique elements corresponding to a different column of the array, and wherein the check vector in row X of the column is the product, in  $GF(2^R)$  of the unique element for that column and  $\alpha^X$ , wherein  $\alpha$  is a primitive element of  $GF(2^R)$ .

2. The apparatus as recited in claim 1 wherein a first element of the plurality of unique elements corresponding to the first column is all zeros, whereby the first column is not covered by the second plurality of check bits.
- 5 3. The apparatus as recited in claim 2 wherein a second element of the plurality of unique elements corresponding to the second column is all zeros except for a one in the least significant position, and wherein the position of the one in each of the plurality of check vectors corresponding to the second column defines the location in the second column that stores the corresponding one of the plurality of check bits.
- 10 4. The apparatus as recited in claim 1 wherein the plurality of unique elements are selected to provide double bit error detection prior to the apparatus identifying a failure of one of the plurality of components.
- 15 5. The apparatus as recited in claim 4 wherein the plurality of unique elements are selected to satisfy the following, where  $\text{check\_vector}(r_x, c_y)$  is the check vector assigned to the bit at row  $x$ , column  $y$  of the array and XOR is bitwise exclusive OR: for any set of 2 distinct rows  $r_1$  and  $r_2$  and any set of 3 distinct columns  $c_1$ ,  $c_2$ , and  $c_3$ ,  $\text{check\_vector}(r_1, c_1) \text{ XOR } \text{check\_vector}(r_2, c_2) \text{ XOR } \text{check\_vector}(r_1, c_3) \text{ XOR } \text{check\_vector}(r_2, c_3)$  is not  
20 equal to zero.
6. The apparatus as recited in claim 4 wherein the plurality of unique elements are selected to satisfy the following, wherein each of the plurality of unique elements is denoted  $\text{UE}[\text{column to which the unique element corresponds}]$ : for any integer  $W$   
25 between 0 and  $R-1$  (inclusive), for any integers  $i$ ,  $j$ , and  $k$  between 0 and  $N-1$  (inclusive), where  $i$  is not equal to  $j$  and  $i$  is not equal to  $k$ , and  $j$  is not equal to  $k$ ,  $\text{UE}[i] \text{ XOR } \text{UE}[j]$  is not equal to the product, in  $\text{GF}(2^R)$ , of  $\text{UE}[i] \text{ XOR } \text{UE}[k]$  and  $\alpha^W$ .
7. The apparatus as recited in claim 1 wherein the plurality of unique elements are

selected to provide single bit error correction subsequent to the apparatus identifying a failure of one of the plurality of components.

8. The apparatus as recited in claim 7 wherein the plurality of unique elements are  
5 selected to satisfy the following, where  $\text{check\_vector}(r_x, c_y)$  is the check vector assigned to the bit at row  $x$ , column  $y$  of the array and XOR is bitwise exclusive OR: for any set of 2 distinct rows  $r_1$  and  $r_2$  and any set of 3 distinct columns  $c_1$ ,  $c_2$ , and  $c_3$ ,  $\text{check\_vector}(r_1, c_1) \text{ XOR } \text{check\_vector}(r_2, c_2) \text{ XOR } \text{check\_vector}(r_1, c_3) \text{ XOR } \text{check\_vector}(r_2, c_3)$  is not equal to zero.

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9. The apparatus as recited in claim 7 wherein the plurality of unique elements are selected to satisfy the following, wherein each of the plurality of unique elements is denoted  $\text{UE}[\text{column to which the unique element corresponds}]$ : for any integer  $W$  between 0 and  $R-1$  (inclusive), for any integers  $i$ ,  $j$ , and  $k$  between 0 and  $N-1$  (inclusive),  
15 where  $i$  is not equal to  $j$  and  $i$  is not equal to  $k$ , and  $j$  is not equal to  $k$ ,  $\text{UE}[i] \text{ XOR } \text{UE}[j]$  is not equal to the product, in  $\text{GF}(2^R)$ , of  $\text{UE}[i] \text{ XOR } \text{UE}[k]$  and  $\alpha^W$ .

10. A memory controller comprising the apparatus as recited in claim 1, wherein the plurality of components are a plurality of memory devices.

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11. A transmission system comprising the apparatus as recited in claim 1 wherein the plurality of components are a plurality of paths on a transmission medium in the system.

12. The transmission system as recited in claim 11 further comprising a source coupled  
25 to the plurality of paths to transmit encoded data blocks and a destination coupled to the plurality of paths to receive encoded data blocks, wherein the source comprises the check bit encoder circuit and the destination comprises the check/correct circuit.

13. A method comprising:

5 selecting a plurality of unique elements of  $GF(2^R)$ , each of the plurality of unique elements corresponding to a different column of an array of R rows and N columns, wherein R and N are positive integers, and wherein the array comprises the bits of an encoded data block including a data block, a first plurality of check bits, and a second plurality of check bits, and wherein each column of the array comprises bits corresponding to one of a plurality of components, and wherein each of the first plurality of check bits is defined to cover the bits in one of the rows of the array; and

10 generating check vectors for each row in the array, wherein the check vector for a bit in row X of a given column is the product, in  $GF(2^R)$  of the unique element for that column and  $\alpha^X$ , wherein alpha is a primitive element of  $GF(2^R)$ , and wherein the check vector defines which of second plurality of check bits covers the bit in row X of the given column.

14. The method as recited in claim 13 further comprising verifying that the plurality of unique elements have been selected to provide single bit error correction subsequent to detecting that one of the plurality of components has failed.

20 15. The method as recited in claim 13 further comprising verifying that the plurality of unique elements have been selected to provide double bit error detection prior to detecting that one of the plurality of components has failed.

25 16. The method as recited in claim 13 further comprising encoding a data block with the first plurality of check bits and the second plurality of check bits.

17. The method as recited in claim 13 further comprising detecting an error in the data from one of the components in the encoded data block and correcting the error.

18. A computer system comprising:

at least one processor;

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at least one memory comprising a plurality of memory devices; and

at least one memory controller coupled to the processor and to the memory,

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wherein the memory controller is coupled to receive data blocks from the processor for storage in the memory and coupled to provide data blocks

read from the memory to the processor, and wherein the memory

controller is configured to generate a corresponding encoded data block in response to receive a data block from the processor, the encoded data

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block including a first plurality of check bits, a second plurality of check

bits, and the data block, and wherein the memory controller is configured to detect an error in data from one of the plurality of memory devices and correct the error using the first plurality of check bits, the second plurality of check bits, and the data block within the encoded data block;

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wherein the encoded data block is logically arranged as an array of R rows and N columns, wherein R and N are positive integers, and wherein each of the N columns comprises data bits from a respective one of the plurality of memory devices, and wherein the first plurality of check bits form a first column of the array, and wherein each of the first plurality of check bits covers a row of the array, and wherein the second plurality of check bits form a second column of the array and are defined to cover bits in the array according to a plurality of check vectors, each of the plurality of check vectors corresponding to a different bit in the array, and each of the plurality of check vectors is an element of a Galois Field ( $GF(2^R)$ ), and wherein the plurality of check vectors are derived from a plurality of unique elements of  $GF(2^R)$ , each of the plurality of unique

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elements corresponding to a different column of the array, and wherein the check vector in row X of the column is the product, in  $GF(2^R)$  of the unique element for that column and  $\alpha^X$ , wherein alpha is a primitive element of  $GF(2^R)$ .

5     19. The computer system as recited in claim 18 wherein a first element of the plurality of unique elements corresponding to the first column is all zeros, whereby the first column is not covered by the second plurality of check bits.

10     20. The computer system as recited in claim 19 wherein a second element of the plurality of unique elements corresponding to the second column is all zeros except for a one in the least significant position, and wherein the position of the one in each of the plurality of check vectors corresponding to the second column defines the location in the second column that stores the corresponding one of the plurality of check bits.

15     21. The computer system as recited in claim 18 wherein the plurality of unique elements are selected to provide double bit error detection prior to the memory controller identifying a failure of one of the plurality of memory devices.

20     22. The computer system as recited in claim 18 wherein the plurality of unique elements are selected to provide single bit error correction subsequent to the memory controller identifying a failure of one of the plurality of memory devices.